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Physical Properties of Five Grain Dust Types

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Physical properties of grain dust derived from five grain types (soybean, rice, corn, wheat, and sorghum) were measured and reported. The grain dusts were obtained from dust collection systems of terminal grain handling facilities and were assumed to be representative of grain dust generated during the handling process. The physical properties reported were as follows: particle size distributions and surface area measurements using a Coulter Counter Model TAII; percent dust fractions less than 100 μm of whole dust; bulk density; particle density; and ash content.

Introduction

The Department of Agricultural Engineering, Texas Agricultural Experiment Station, Texas A&M University has been involved in the study of grain dust explosions and cyclone design for a number of years. Grain dust physical properties have been studied to assist in explaining phenomena associated with laboratory explosions using various dust fractions derived from different groups. In addition, cyclone efficiency evaluations and design criteria require substantial data on dust physical properties.

In order for grain dust explosions to occur, four ingredients must be present. These ingredients are fuel, confinement, ignition source, and oxygen. The fuel for a grain dust explosion is grain dust in suspension above the minimum explosive concentration (MEC). Containment is a requirement for an explosion to occur in that it allows a buildup of pressure resulting in rupture of the confinement. However, containment is also necessary to achieve the MEC of grain dust, which is in the range of 50 g/m^3 (*1*).

The dispensibility and combustion rates of dust are governed by chemical and physical properties of the dust involved. How easily and uniformly a dust is suspended into the air depends on its particle size distribution and density. The rate of combustion is highly dependent on the exposed surface area of dust that can readily react with oxygen. These physical properties are the key to defining dust explosibility and developing are the key to defining dust explosibility and developing an explosion hazard indication.

Different laboratory techniques have been employed by various researchers in an effort to quantify dust characteristics. Plemons (*2*) and Martin (*3*) performed particle size analysis by wet sieving, dry sieving, and Coulter counter techniques. Wade, Hawk, and Watson (*4*) also used Coulter counter techniques to determine particle size distributions. A summary of a portion of the work done in this area is shown in Table 1.

By far, the most explosive grain dust fraction is that less than 100 μm (*5*). The smaller fractions of grain dust are most explosive because the surface area per unit mass increases as the particle size decreases. However, larger fractions (250–500 μm) in sufficient concentrations can be made to explode. The surface areas of grain dust have been determined by Deshpande and Matthews (*6*) and Martin (*4*). Each of these researchers used adsorption techniques and Martin also used a light obscuration method. Martin found that the surface area for grain dust varied from 0.6 to 0.9 m^2/g. Deshpande and Matthews found that the surface area for grain dust ranged from 0.6 to 1.96 m^2/g.

The bulk density and particle density affect the handling and conveying characteristics of particulate material. Chang and Martin (*7*) developed models to predict the density distribution and weight of grain dust in self-packed columns. They found that the bulk density of self-packed dust increased linearly as the depth of the pile increased. These tests were performed on wheat, sorghum, and corn dust. Figure 1 shows the relationship between the vertical density distribution of grain dust in a self-packed grain dust column.

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PSDs of the five dust types are described by the mass median diameter and geometric standard deviation of the individual distributions in Table 6. Table 6 also contains the remaining information available from the Coulter Counter procedure, i.e., the mean, mode, skewness, and kurtosis of the particle size distributions.

Also available from the Coulter Counter procedure are the differential and cumulative histograms of each of the PSD. Figures 2 through 6 show the histograms for soybean, rice, corn, wheat, and sorghum dusts, respectively.

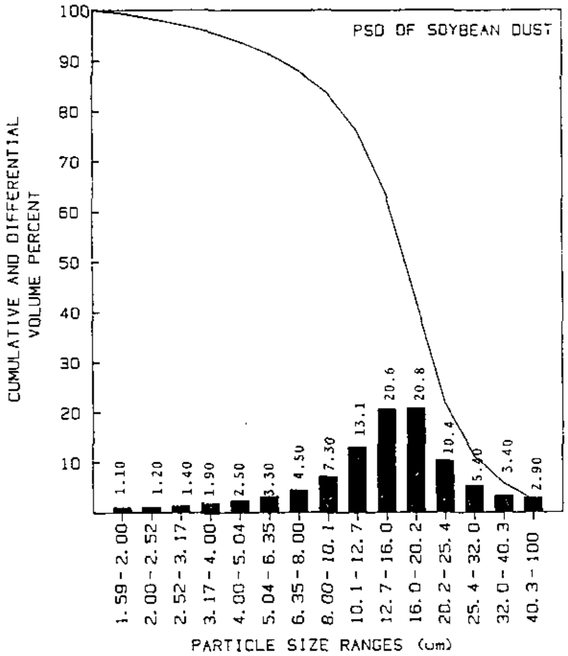

FIGURE 2. Differential and cumulative histograms for the particle size distribution of soybean dust <100 μm.

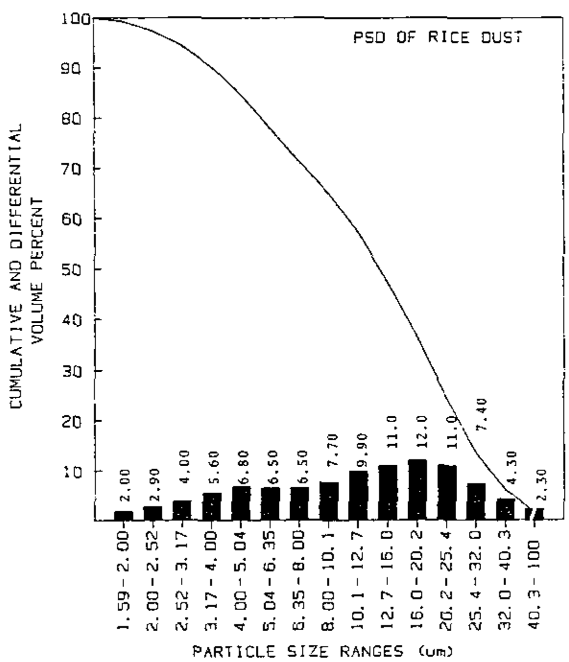

FIGURE 3. Differential and cumulative histograms for the particle size distribution of rice dust <100 μm.

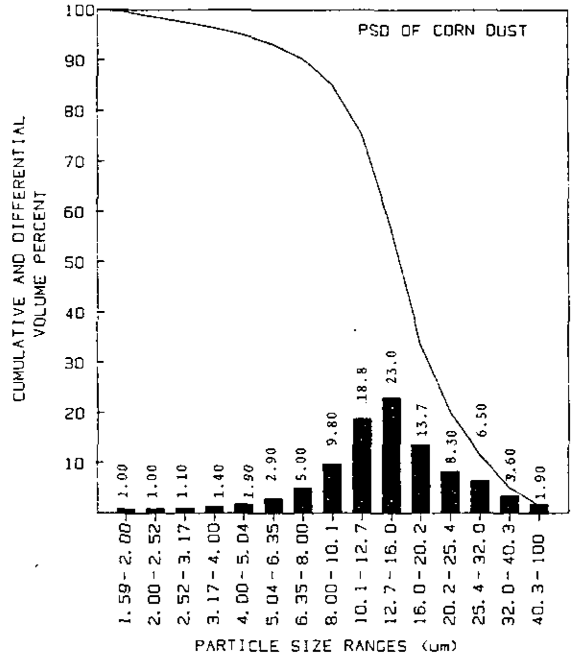

FIGURE 4. Differential and cumulative histograms for the particle size distribution of corn dust <100 μm.

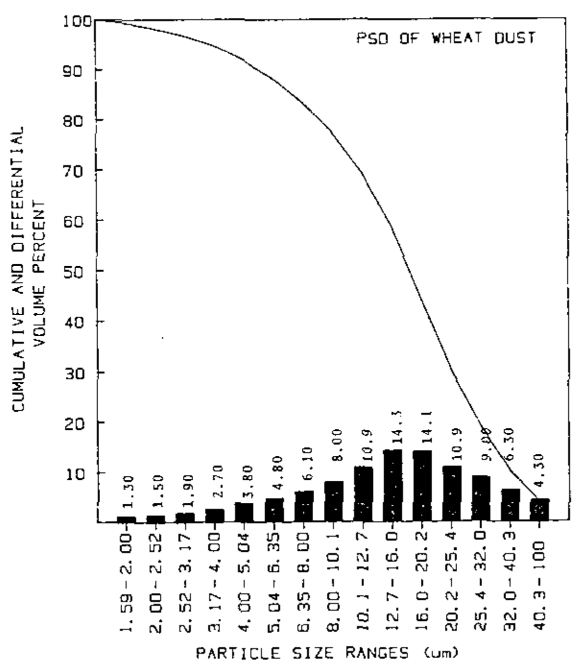

FIGURE 5. Differential and cumulative histograms for the particle size distribution of wheat <100 μm.

Table 6. Particle size distributions of soybean, rice, corn, wheat, and sorghum dust, < 100 μm using the Coulter Counter, Model TAII.

	Soybean	Rice	Corn	Wheat	Sorghum
Mean, μm	13.6	10.7	13.2	13.4	14.0
Median, μm	14.8	12.1	13.6	14.7	15.7
Mode, μm	16.1	18.0	13.7	15.8	18.1
SD, μm	1.87	2.24	1.80	2.08	2.16
Skewness	−0.810	−0.830	−0.860	−0.790	−0.720
Kurtosis	1.90	2.58	1.69	2.34	2.96

Surface Area

Surface area is an important physical property related to the explosibility of grain dust (*6*). Traditional methods of surface area determination of particulate material, such as nitrogen adsorption, have been successfully utilized for inorganic material. However, grain dusts are largely composed of organic components and it was considered likely that organic dust would absorb nitrogen resulting in false surface area measurements. In an attempt to obtain accurate measurements of surface areas for soybean, rice, corn, wheat, and sorghum dust, the Coulter Counter procedure (*10*) was used.

Equation (2) was used to determine surface area, in square meters per gram of dust less than 100 μm, as a function of particle density, differential volume percentage, particle diameter, and an assumed particle shape for the grain dusts.

$$\mathrm{SA} = \frac{Y_i(\mathrm{SF})}{100 \exp\{\log X_i + (\log 2)/6\}\mathrm{DS}} \qquad (2)$$

where SA = surface area (m^2/g) of grain dust particles less than 100 μm, Y_i = differential volume percent in current range, X_i = diameter (μm) at lower edge of current range, DS = particle density (g/cm^3), and SF = shape factor. The differential volume percentages and particle diameters were obtained directly from the PSD data and particle densities were determined as previously discussed.

The shape factor SF was determined by using a calibration material (zinc oxide) having a known surface area (as determined by nitrogen adsorption) and particle density (*11*). The differential volume percentages and particle diameters were obtained by determining the PSD of the calibration particles. The appropriate shape factors were subsequently calculated by using Eq. (2). The surface areas of each of the five types of grain dust were assumed to have a shape factor identical to that of the calibration particles.

The means, standard deviations, and coefficients of variation of the surface areas for three samples of each of the five types of grain dust are presented in Table 7. The surface area for rice dust less than 100 μm was greater than that of the other dusts. This is to be expected, since the rice dust exhibited the smallest mass mean diameter of the five types of grain dust.

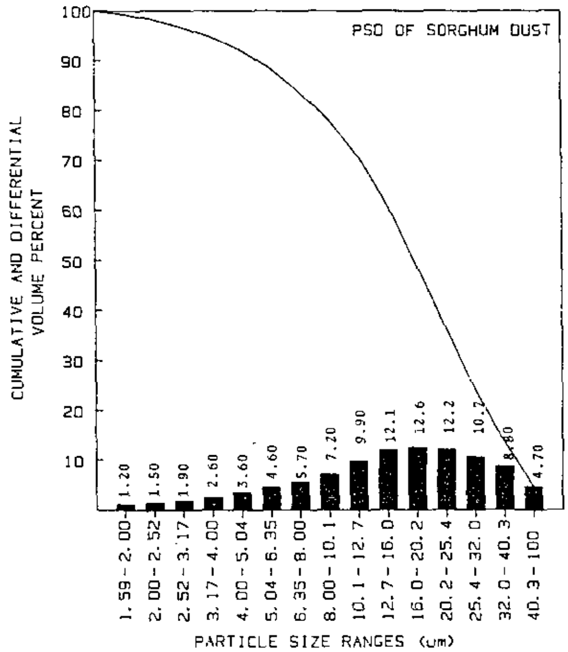

FIGURE 6. Differential and cumulative histograms for the particle size distribution of sorghum dust <100 μm.

Ash Content

The percentage of ash present in a grain dust sample is a measure of the inorganic fraction present in whole grain dusts.

Ash contents were determined for each of the five grain dusts by using a baffle furnace procedure. A preweighed sample of grain dust was placed in a drying oven to remove the moisture. The dried sample of grain dust was weighed and placed in a baffle furnace for 120 min at 550°C. The samples were cooled in a desiccator before reweighing. The percentage of ash was calculated by using Eq. (3).

$$\%\ \text{ash} = \frac{\text{Weight of ash}}{\text{Total weight of dry dust}} \times 100\% \qquad (3)$$

Table 7. Surface areas for soybean, rice, corn, wheat, and sorghum dusts < 100 μm by the Coulter Counter method, Model TAII.

Dust	$\bar{X}$, m^2/g	SD, m^2/g	CV, %
Soybean	0.869	0.003	0.37
Rice	1.092	0.055	5.05
Corn	0.826	0.006	0.74
Wheat	0.862	0.018	2.07
Sorghum	0.866	0.040	4.59

The means, standard deviations, and coefficients of variation of six samples of each of the five types of grain dust are presented in Table 8. Ash contents of the whole grain dusts ranged from 5.12% for soybean dust to over 30% for rice. This would indicate that rice dust contains a large amount of inorganic matter.

Table 8. Ash contents of soybean, rice, corn, wheat, and sorghum dusts using a baffle furnace.

Dust	Ash content, %	SD, %	CV, %
Soybean	5.2	0.223	4.35
Rice	30.6	0.414	1.36
Corn	12.0	0.173	1.40
Wheat	7.19	0.495	6.89
Sorghum	9.59	0.376	3.90

Conclusion

Physical properties of grain dust play an important role in explaining dust explosibility and handling characteristics. Analysis of interaction between these properties will aid in the development of an explosion hazard indicator and in the design and evaluation of dust handling/separation equipment.

Results of the laboratory analysis of wheat, corn, rice, soybean, and sorghum dust are as follows: bulk density, 0.150–0.308 g/cm^3; particle density, 1.43–1.69 g/cm^3; % < 100 μm (by weight), 34.3–50.6%; mass mean diameter (dust < 100 μm), 10.7–14 μm; ash content, 5.12–30.6%.

Future Research

A promising dust control method for grain elevators is the addition of oil to grain. Over one hundred elevators in the midwest are already applying mineral oil to all their grain and preliminary results have proven beneficial. The Food and Drug Administration has approved an additive level of 0.02% by weight food grade (white) mineral oil. Further research at Texas A&M University includes a computer simulation of the operation of elevator dust control systems for comparison of the cost of conventional dust control to oil additive costs. Also, grain samples taken at elevators using oil additives are being analyzed as to dust content and particle size distribution. These data will be used in future work concerning detection of the oil concentration on grain and effects of various concentrations of foreign matter.

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